

10 Mpc QSO Absorber Correlations at $z \sim 3$

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Abstract. We present results from a survey of the Ly α forest at $2.15 < z < 3.26$ toward ten QSOs concentrated within a 1° field. We find correlations of the Ly α absorption line wavelengths between different lines-of-sight over the whole redshift range. This indicates the existence of large-scale structures in the Ly- α forest extending at least over $\sim 36 h^{-1}$ comoving Mpc in the plane of the sky, as may be expected from recent large scale structure simulations.

1 Introduction

Comparison between spectra of multiply lensed quasars [20, 21] or close quasar pairs [1, 4, 6, 7] indicate that the numerous narrow Ly α absorption lines observed in quasar spectra are produced in large tenuous clouds with diameters $> 50 h^{-1}$ kpc ($H_0 \equiv 100h$ km s $^{-1}$ Mpc $^{-1}$, $q_0 = 0.5$ and $\Lambda = 0$ assumed throughout). Their association with galaxies is unclear [2, 10, 11, 19]. There has been much effort made to examine spatial structure in the Ly α forest along isolated lines-of-sight ([9] and references therein). A complementary approach is to examine structure between adjacent lines-of-sight, which has already revealed structures on the scale of several Mpc outlined by C IV absorbers [5, 22]. Crotts [3] searched for spatial structure in the Ly α forest at $2.2 < z < 2.6$ on the scales of several arcmin separation using 4 QSOs separated by at most 440 arcsec. He found clustering for velocity separations of $\Delta v \approx 100$ km s $^{-1}$ for $W_0 \geq 0.4$ Å absorbers and for $\Delta v \approx 400$ km s $^{-1}$ for stronger absorbers ($W_0 \geq 0.8$ Å). A new analysis method, using pixel correlations and based on the same SGP data as used here, reveals the C IV cluster at $z \sim 2.3$ which was found in [22], as well as a void toward four lines-of-sight at least $36 \times 24 h^{-2}$ comoving Mpc in extent at $z = 2.97$ [12].

Here we present the 2-point correlation function of the Ly α forest toward ten $z > 2.3$ QSOs within a 1° field near the south Galactic pole. A more complete description of the statistical methods and results of this work will be presented elsewhere [23].

2 Data

The observational data consist of the 10 highest signal-to-noise ratio 2 \AA resolution spectra covering the Ly- α forest; they were obtained during a parallel study [22] on the large scale structure revealed by C IV absorbers.

We exclude lines within 5000 km s^{-1} from the background QSO to avoid uncertainties linked with the “proximity effect” (reduced line number density and equivalent widths), and all Ly α lines corresponding to known metal absorption systems from [22]. Apart of these restrictions, we use all of the Ly α absorber information we have between Ly α and Ly β emission wavelengths, regardless of the signal-to-noise ratio of the data.

The sample contains 383 Ly α lines at $2.15 < z < 3.26$, at a rest equivalent width detection limit of $W_0 \geq 0.1 \text{ \AA}$ (5σ). The data are only complete to $W_0 = 0.5 \text{ \AA}$. The number density of $W_0 \geq 0.5 \text{ \AA}$ lines is typical, being proportional to a power law [13] $d\mathcal{N}/dz \propto (1+z)^\gamma$, $\gamma = 2.5 \pm 0.8$. We find no large voids at any W_0 (following [15]).

3 Statistical analysis

We first calculate the 2-point correlation function of the comoving separation of the Ly α absorbers. The comoving separations are evaluated from the redshift of the absorption lines and the separation between the lines-of-sight using the standard formula [3]. In order to estimate the significance of any signal, we constructed control samples free of correlations between absorbers along different lines-of-sight by shifting the observed absorption line wavelengths along each line-of-sight by a random amount varying between 6 and 182 \AA (or 2 and $52 h^{-1}$ comoving Mpc or 420 and 11000 km s^{-1} along the line of sight at $z \approx 3.25$). This procedure allows us to use a much larger line sample than from a complete survey, which would be limited to only 149 lines at $W_0 > 0.5 \text{ \AA}$ for 5σ significance, while keeping the observational limitations of spectral resolution and signal-to-noise ratio. The dispersion about the mean per bin was measured directly from the Monte Carlo simulations, typically using 100–1000 iterations. Monte Carlo simulations show that the distribution of pair counts in a given bin is well-approximated by a Gaussian. We find no evidence (for any binning) for three dimensional structure in the Ly α forest using the two point correlation function over $2 \sim 52 h^{-1} \text{ Mpc}$.

We next calculate the 2-point correlation function of the velocity differences of all possible pair of Ly α lines, testing for structures which are in the plane of the sky. We only include absorber pairs which lie along *different* lines-of-sight, in order to avoid resonances between Ly α and unidentified metal lines in the same spectrum, and to concentrate on structures with transverse spatial extent. We find an excess of pairs of $W_0 \geq 0.1 \text{ \AA}$ Ly α absorption lines with velocity differences $50 < \Delta v / \text{km s}^{-1} < 100$ compared to the control sample at the 3.3σ level. It is noteworthy that we do not detect any significant signal

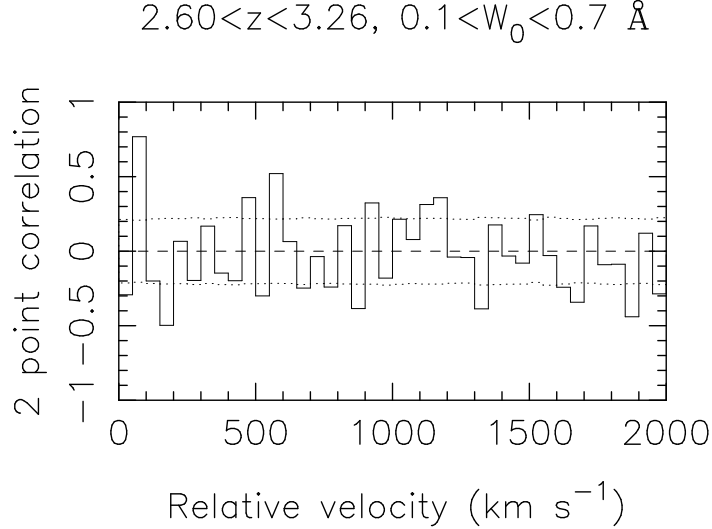


Figure 1: The two-point correlation function in velocity space for the SGP data at $2.60 < z < 3.25$ and $0.1 < W_0 < 0.7 \text{ \AA}$. Only absorber pairs along *different* lines-of-sight are included. The 1σ scatter measured from fluctuations in the randomized data is shown by the dotted lines. The $50 < \Delta v < 100 \text{ km s}^{-1}$ feature is significant at 3.7σ , with a probability of occurring in *any* bin of $P = 0.001$.

at velocity splittings $\Delta v < 50 \text{ km s}^{-1}$ under any circumstances. The signal is not present at $2.15 < z < 2.60$, and is strongest at $2.60 < z < 3.25$ for lines $0.1 < W_0/\text{\AA} < 0.7$ (Fig. 1), at the 3.7σ level, with the probability of finding such an excess in *any* bin of $P = 0.001$. We find no significant dependance of the correlation function on the angular separation.

4 Discussion

The most intensive previous study for correlation between close QSO sightlines used 4 QSOs[3], with similar resolution and slightly lower signal-to-noise ratio, but at somewhat lower redshift and much smaller angular separation (less than 7.2 arcmin) than our work. Crotts found an excess of pairs of $W_0 \geq 0.4 \text{ \AA}$ lines with $\Delta v < 100 \text{ km s}^{-1}$ and of $W_0 \geq 0.8 \text{ \AA}$ lines with $\Delta v < 400 \text{ km s}^{-1}$, but no clustering for weak ($W_0 < 0.4 \text{ \AA}$) lines. We find that including weaker lines to $W_0 = 0.1 \text{ \AA}$ strengthens the clustering significance. More data are needed to investigate such trends and resolve these discrepancies. We have used our software to re-analyse published linelists from smaller, independent datasets [3, 17]. These are by far the two largest published data samples useful for probing correlated QSO Ly α absorption similar to our data. The two point

correlation function similarly reveals excesses at $50 < \Delta v < 100 \text{ km s}^{-1}$ in both of these independent datasets at $2 - 3\sigma$ significance.

Our key finding is that Ly α absorber correlations extend over scales of 41 arcmin ($\sim 9h^{-1}$ Mpc in the plane of the sky at the $z = 3$ frame or 36 comoving h^{-1} Mpc). Simulations of the growth of cosmological structures [8, 14, 16, 18] do indicate that filaments of dark matter and gas extend over several Mpc. These simulations may underestimate the true correlation length of the structures traced by the Ly α forest, if it is comparable or larger than the size of the box in which they are carried out. Our observations indicate that it may well be the case, as all the volumes used so far are small compared to the spatial extent of our survey.

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